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REVIEW ARTICLE

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Review on Process Parameters of Rapid Manufacturing Process and Their Effects on Properties of Fabricated Parts

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Abstract: 3D printers have become a popular production approach in compared to traditional methods. One of well and commonly used additive manufacturing processes is fused deposition modelling (FDM). The FDM method of manufacturing parts has restricted capabilities such as model manufacturing and prototyping due to the absence of mechanical properties of the composite polymers used as dropping ingredients .Mechanical properties of thermoplastics components such as surface roughness, breaking elongation, tensile strength, and flexural strength are all explored. FDM is Fast Prototyping technique in which a plastic filament is molten in the 3D printer extruder and deposited on the 3D printer's building platform to produce the object layer by layer. The mechanical qualities of items made with thermo plastic filaments and the FDM process were explored in depth in this work. The literature on developing thermoplastic fibers with better physical qualities than strands for 3d printing technology was reviewed. As a result, thermoplastic items made throughout this manner are more likely to be employed in a broader range of applications.

Keywords: FDM, Thermo plastics, 3D printing, Infill percentage, Surface roughness, Impact Strength, Flexural strength.

I. INTRODUCTION

3D printing technology has advanced quickly in recent years in aviation, transportation, electronic parts, medical, and a range of other disciplines. 3d printing manufacturing technology that creates direct prototypes by layering multiple layers together of challenging structural components while lowering the product cycle and costs, in contrast to standard compositional machining technologies (e.g., twisting, grinding, cutting) [1].Fused deposition, the most extensively used 3d printers' method, offering advantages in thermoplastic modeling.FDM is a layer-wise 3-D printing process created by Stratasys for producing dense geometrical objects.FDM has grown in popularity as a consequence of its versatility and high efficiency for implementing a variety of components. In this procedure, filament material is extruded single layer by layer, using a needle on a partially created component in a semi-solid state. First, the Stereolithography (STL) file format of the component model is created in the geometry generation program [2]. FDM is a popular rapid prototyping (RP) technology for creating complex geometrically optimal parts in a small space of time in industries. A range of process parameters greatly impact the quality, reliability, and attributes of products created using the FDM technology. Exploring FDM process settings is crucial for achieving required quality characteristics in FDM-produced components. The research of the influence of 3D-printed process variables on FDM component response characteristics aids us in measure the extent of processing factors. As a consequence, enhanced printing consideration will be taken into account when selecting a printer [3].To produce the tool geometry motion, only two-dimensional contour data is needed. The motion of the liquefier tip is controlled by a three-axis mechanism. It deposits the initial layer by moving in the X-Y direction in line with the system's tool path. This technology is referred to as Solid Freeform Fabrication in American Society for

Testing and Materials, (ASTM) F42 Modern Manufacturing Technologies nomenclature. According to the ASTM F42 Additive Manufacturing Technologies terminology, Fused Filament Fabrication is the name given to this technique. FDM printed parts have traditionally been used for reduced prototypes, such as toys for children. The process is now being developed to print parts for real-time industrial applications thanks to technological breakthroughs. A design approach like fused filament fabrication (FFF) is used in Wide Area Manufacturing Technologies [4]. Figure 1 shows a building platform, ahead of the liquefier, a print bed, and a spool of construction material are all part of the deposition modeling process. Steps followed in FDM process are discussed below.

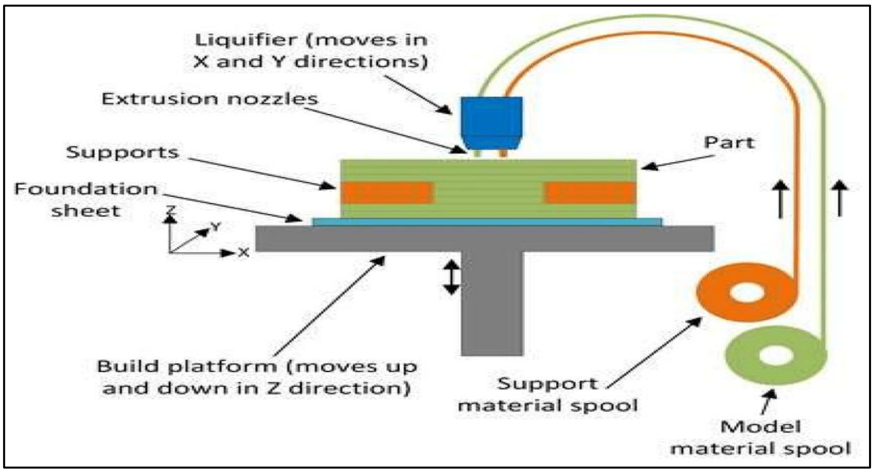

Figure.1. Fused deposition modeling (FDM) setup [4]

- A spindle of polymeric filament is originally fed into the machine. The heat gained into the extrusion head and melts in the aperture after the tip reaches the appropriate temperature [5].
- The ejection head is attached to a point, allowing it to move in three different directions: X, Y, and Z are the three directions it may traverse in. Moulded tiny wires of molten material are inserted layers by layer in pre-set locations to freeze and harden. For expedite the cooling of the material, cooling fans attached to the extruder were utilized generally[6].
- To fill a region, many sweeps are required like colouring a rectangle with a marker. When a layer is formed, the surface or extrusion head in other machine settings slips down and a new layer is implanted. This operation is continued until the item is finalized [7].

Table 1: Different FDM process parameters

Above the "all-purpose" orientation, including

Ref.	*Different FDM Method parameter*	*Explanation*
[8]	Layer thickness	Layer thickness defines the height of layers put after extrusion from nozzle tip slow by Z-direction & based on material, extruded nozzle tip diameter. It is normally smaller than the width of extruder nozzle tip.
[9]	Build Orientation	The part is oriented in the construction platform through the FDM machine's X, Y, Z direction.
[10]	Raster Angle	Extruded material is deposited when the X-direction raster angle is constructed. It usually varies as of 00 to 900.
[11]	Air Gap	It is a gap on layer of the printed FDM part between 2 adjacent tool paths.
[12]	Extrusion temperature	The rate upon which thermoplastic filament components are treated in the nozzle before extrusion in the FDM process.
[13]	Print Speed	It's the pace at which a nozzle tip travels in the XY plane of a construction platform to deposit material.
[14]	Infill pattern	An infill pattern is a material accumulation pattern used to construct the interior structure of an FDM produced component. Infill patterns commonly used are cross, diamond, linear infill& honeycomb patterns.
[15]	Infill density	In general, the surface levels of FDM printed sections are strong, but interior configuration is not certainly solid, that can be sparse & with different patterns, shape & sizes of infill density therefore indicates the solidness of the FDM printed part's internal structure.
[16]	Nozzle diameter	It is the diameter of the extruder's nozzle tip.
[17]	Width of raster	The thickness of beads deposited with path of the extruder device is mainly depends on the extruder nozzle tip diameter.

II. LITERATURE REVIEW

Numerous authors have contributed work, which is listed below:

Magri, et al. (2021) [18] mentioned that when it comes to items made using short carbon fibre (CF)-reinforced polylactic acid, the nozzle's temperature, and the location of the infill lines for composite material and PLA-CF polylactic acid carbon fiber. In which composite test bars were developed under extreme conditions. PLA-CF offers stronger tensile qualities than PLA because high modulus CFs has a stabilizing impact.

For both PLA and PLA-CF, a nozzle temperature of 230 C produces the best tensile characteristics. As a result, this temperature was chosen to investigate the impacts of different sample bar orientations [18].

both PLA and PLA-CF, the combined effect of setups in comparison to the longitudinal plane of the sample bar determines the maximum thresholds of shear qualities. [18].

The microstructural and mechanical qualities of produced items can be altered by annealing. The degree of crystallinity of specimens annealed under various circumstances was determined using differential scanning calorimetric measurements.

In PLA and PLA-CF materials, annealing promotes crystallinity, with lower processing temperatures yielding higher values [18].

Kamaal, et al. (2021) [19] stated that the mechanical characteristics of 3-dimensionalCF-reinforced poly - lactic acid (PLA) as a function of FDM process parameters for copolymers. Rebuilding direction, infill percent, and layer height are all process variables investigated in this study, and they all have an influence on the mechanical qualities of the final product. The experiment looked at tensile and impact strength as response characteristics. Using Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS) assessment, an ideal combination of parameters for achieving maximum strength while using the least amount of material was discovered. For additive manufacturing techniques, CF-reinforced PLA composites fibre 1.75 mm diameter was employed.

Peng, et al. (2021) [20] stated that FDM offers distinct benefits in the fast prototyping of thermoplastics utilized in a variety of applications.

Despite significant efforts to improve FDM, weak interlamination bonding, and lackluster productivity of primary materials such as ABS and polylactic acid, and others limit the mechanical qualities of printed components of different materials. To enhance the qualities of produced objects, adding fibres to thermoplastic and forming huge filaments has been suggested. To address equipment and process limitations, high-temperature polyether-ether-ketone (PEEK) and its composite materials have recently been proposed for FDM. However, there has been little research into the implications of mechanical constraints for FDM-3D printing in which fibre reinforced PEEK composites. PEEK polymer filament reinforced with different weight percentages CF and glass fibre (GF) was developed in this study [20].

Nagendra, et al. (2020) [21] stated that FDM, a common SLS manufacturing process, for high polymeric composites in medical applications, it appears to be a cost-effective and efficient three-dimensional (3D) printing standard. This study developed an FDM process for printing polyesters material. An axial test with four parameters and three phases was used to study the effects of tool rotational speed, layer height, print temperature, and filler ratio on elastic characteristics. At a printing speed mm/s, a film thickness of 0.2 mm, maximum temperature of 370°C, and a dispensing ratio of 35 per cent, the PEEK specimens had the best tensile properties. The contact and torsion tests were also carried out under ideal conditions, confirming that printed PEEK specimens have the necessary mechanical properties.

Wang et al. (2020) [22] stated that FDM is an extensively used 3d printing process that can be applied to a variety of sectors, as per the industry. Even though a lot of study has been done on the impacts of FDM process conditions on material tensile modulus, there are a few things to keep in mind. The first is the effect of system parameters on the complex simulation properties of epoxy materials, which is extremely important and crucial when thermal effects are prevalent. Another is how process activities have an influence on the tensile modulus of materials. To define the tensile characteristics and vibrant material properties, tensile tests and micro structural investigations are used of composite materials under a range of FDM process parameters, such as print angle, weight percentage, fill rate, and operating temperature. Experimentally, the effects of FDM input settings on material physical behavior are examined.

Chacón, et al. (2019) [23] stated that several manufacturing factors influence the mechanical characteristics of a finished product. The goal of this research is to examine how the formability, film thickness, and fibre volume content of 3-d - printed continuous fibre reinforced composites components made on an additive manufacturing process affect mechanical behavior. The dynamic strength of the manufactured exhibits is investigated using shear and multiple bend tests. The influence of process factors on failure modes are investigated using SEM pictures of shattered surfaces. The mechanical performance of nylon samples is found to be slightly affected by layer thickness. Unstrengthen materials have less rigidity than continuous fiber reinforced samples. Flat samples offer superior strengths and elasticity results than on-edge samples, and carbon fiber composite have the highest load bearing capacity, with higher stiffness.

Akhoundi, et al. (2019) [24] stated that FDM 3D printing was used to build thermoplastic compounds with constant reinforcing fibers. The initiation and implementation of continuous fibre ingestion (glass fibre yarn in this example) and thermoplastic filaments. Fiber glass yarn is supplied into the hot molten metal domain (of the nozzle) through an aperture, in which it is covered and (partially) saturated with the melted polymeric component. The thermally strands are next template to generate layers, and then the required sections.

Because fibre volume content determines the material properties of printed composite goods, it is vital to regulate fibre volume content to manufacture a component with enhanced mechanical properties and to accurately anticipate the elastic modulus of printed components. As a result, fibers arrangement was thoroughly explored as the most important parameter determining fiber content in this study, and the rectangular design was discovered to be the most preferable option [24].

Wang, Sanders, etal. (2018) [25] stated that FDM with commercially available propylene (PP) filament was used to create the specified tensile and flexural strength test samples. As printing factors, the extrusion process (200, 250 °C), printing speed (45, 90 mm/s), and sheet thickness were also investigated (0.1, 0.3 mm). According to differential scanning calorimetry, FDM printed PP samples had less -crystals and far more -crystals than injection moulded (IM) PP samples.

Raising the temperature, lowering speed, and increasing the thin layer height facilitated molecular mobility at the plug ins, resulting in a smaller neck size inside the printed components, as per transmission electron microscopy [25].

According to the results, the IM PP samples were dense than the FDM PP specimens. The FDM PP specimen density stayed unchanged. At a relatively high extrusion temperature, the mechanical properties of the PP print were less impacted than those of the IM PP [25].

Gebisa, et al. (2018) [26] stated that the processing settings appear to have an impact on the characteristics of FDM-produced items. These processing settings offer contradictory benefits that must be studied.

The purpose of this study is to see how these factors affect the flexural characteristics of FDM-produced components [26].

This study refers to high ULTEM 9085 materials, which are relatively new in the aviation, defense, and industrial applications [26].

This study takes into account the air space, raster thickness, inclination angle, degree of contours, contouring width, and a two - level factorial design. According to the findings, the raster angle and width have the most impact on the material's flexural characteristics. With an air gap of 0.000 mm, a raster thickness of 0.7814 mm, a raster tilt of 0, a contour statistic of 5, and a contour dimension of 0.7814 mm, the flexural strength was 127 MPa, the implications yield strength was 2400 MPa, and the elastic strength was 0.081 mm [26].

Johnson, et al. (2018) [27] stated that the consumer's access to material characterization data has been considerably hampered to until. Due to the low initial capital cost and comparatively low operating expenses, consumer level 3D printers are an asset to entrepreneurs, small enterprises, institutions, college students, and enthusiasts. Material qualities and print settings for commercial grade 3D printers and the filaments offered for their usage are normally thoroughly documented. Consumer 3D printers, on the other hand, often have little or no access to mechanical test data for the materials they use.

The researchers detail their efforts to bridge a knowledge gap in the mechanical characteristics of consumer-level 3D printer filament in this research. On samples created by two commercially accessible 3D printers, ASTM Tensile (D638) tests were performed. PLA, ABS, PETG, different nylons, Polycarbonate/ABS, and ASA filaments were among the materials examined. To test for tensile qualities, samples were printed with infill percentages ranging from 15% to 100% [27].

III. PARAMETERS OF FDM PROCESS

Following are the process of FDM process [28]:

A. Process Parameters

- **Infill density**

The exterior layers of 3-D printer piece are solid. However, inner formation, generally properly known as infill.

- **Raster width**

It based on the extrusion nozzle diameter & specified the thickness of the deposition beads.

- **Print speed**

The distance travelled by the extrusion lengthwise in the XY plane for every unit time is referred to as extruding.

- **Thickness of layer**

It is an elevation of deposited layers with Z-axis, that is normally perpendicular axis of the FDM system.

- **Infill pattern**

In components, various infill patterns are utilized to create a solid & durable interior structure.

- **Raster orientation**

It is a distribution beading with relation to the X-axis of the FDM build substrate.

- **Build orientation**

Construct orientation is described in terms of X, Y, & Z-axes as the approach to accommodate the part of the building platform.

- **Air gap**

It is the difference between 2 nearby rasters on a deposited layer [28].

B. *Material parameters*

- **Polymer type**:

The FDM method is extremely appropriate for printing amorphous polymers which are rapidly solidified through a smaller amount of reduction.

The solidifying of semi-crystalline polymers takes extended time-varying on the level of crystalline &cooling rate shown in figure 2[28].

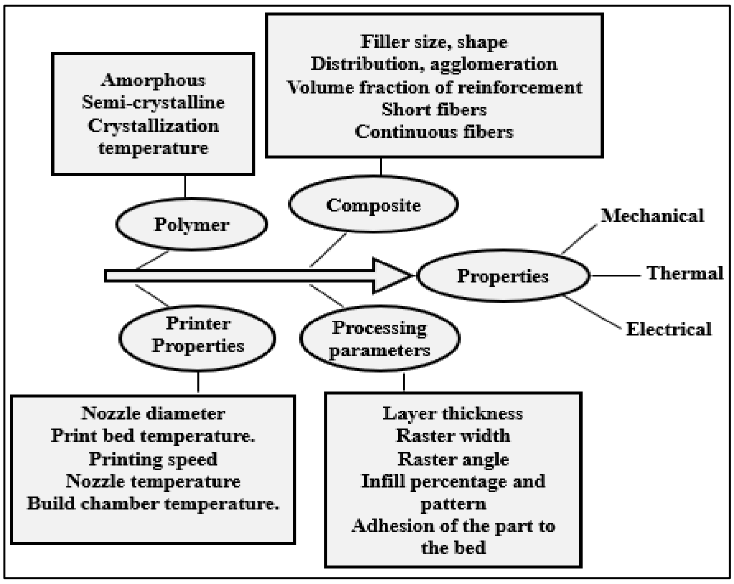

Fig.2 Various parameters influencing the properties of FDM printed parts [28]

C. Print & Machine parameters in FDM [29]

Following are the Print & Machine parameters in FDM.

- **Infill density**

The quantity of material which is managed within constructs the element.

- **Raster to raster gap**

The difference in the same layer between two adjacent grids. The similarity of rasters describes the negative air gap.

- **Number of contours**

The number of outer structures of an element.

- **Raster width**

It is applied to fill interior sections of the part.

- **Layer thickness**

The thickness of layer added refers to it.

- **Build Orientation**

It defines preference of element in a build platform with respect to X, Y, Z axis [30].

- **Raster angle**

Raster direction comparative to X-axis of building table [30].

IV. MECHANICAL PROPERTIES OF FDM

It's critical to understand the mechanical properties of materials to make the most use of them, and these attributes should be tweaked as needed depending on the application. Mechanical qualities of materials include tensile strength, flexural strength, deformability, yield strength, stiffness, hardness, and other physical properties of materials. The printing settings and additive and additive concentrations are the two categories of mechanical attributes that may be found in FDM goods[31].The impact of 3d - printed settings on physical behavior of three-dimensional 3D objects has gotten a lot of attention. The impacts of additive, which is another key problem in determining the strength of components generated using the FDM technique, on the material characteristics for elements made using the FDM technology, were collated in this study[32].

A. Static Mechanical properties

The impacts of FDM parameters on tensile strength of Acrylonitrile-butadiene-styrene (ABS) parts managed by FDM are experimentally. They estimated the tensile strength of the ABS component is individually on the scales of (65-72) % and amplitude (80-90) % by using optimum process parameters [33].

B. Dynamic mechanical properties

FDM manufactured parts matter to cyclic loading & dynamic conditions, like in vibrating machinery & transport applications. At three different isothermal temperatures, frequency sweeps from 10 Hz to 100 Hzwere used [34].

V. Comparative Analysis of Mechanical Properties in FDM of different materials

This table2 shows the tensile strength and fiber volume percentage of various materials, such as Acrylonitrile butadiene styrene ABS, Polylactic Acid PLA, and polyethylene terephthalate glycol PET-G. Along with materials production procedures involving the proportional mixing of thermoplastic polymeric materials.

Table. 2: Tensile strength and fiber volume % for different materials

Reference	*Material*	*Fiber volume percentage (%)*	*Tensile strength (MPa)*
Chacón, et. al (2020)[23]	ABS	1.5	40.2
Mahajan and Cormier (2015)[32]	EPOXY	10	66.2
Nagendra, et. al. (2020)[21]	NYLON	2	51.45
Rajpurohit and Dave (2019)[30]	PLA	1	43.65
Wang et al. (2020)[22]	PET-G	20	32.79

Variation in Tensile strength in MPa for some matrix materials like ABS, EPOXY, NYLON, PLA and PET-G as shown in figure 4. Due to the use of different additives and additive ratios such as carbon fibre reinforced silicon carbide, EPOXY and NYLON have higher tensile strength than ABS and PLA (Cf-SiC).

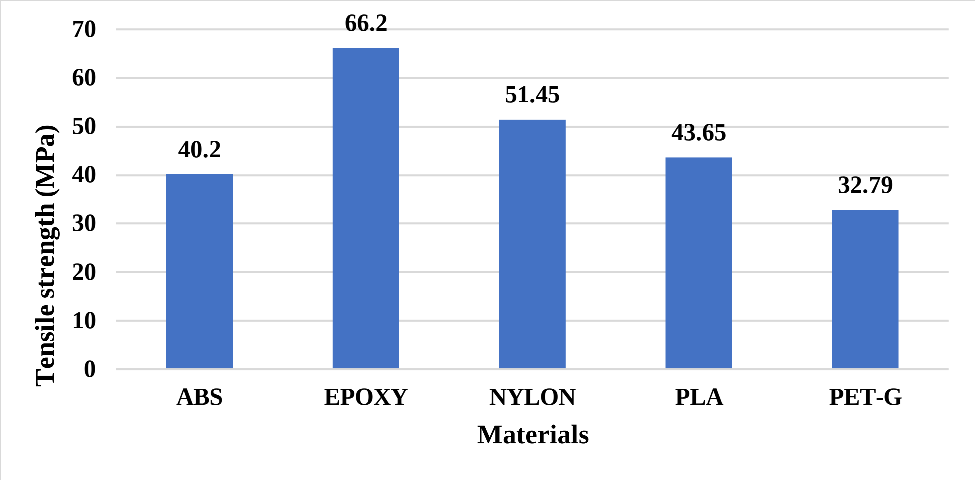

Fig. 4 Tensile strength for matrix materials [34]

As the comparative analysis of some material with respect to Flexural strength in MPa and their breaking elongation after the test specimen has been broken, the ratio between the modified length and the initial length is calculated. It describes a material's capacity to withstand changes in shape without cracking in terms of percentage (%) in flexural strength comparison Nylon and PLA shows high flexural strength value than ABS and PET-G and in breaking elongation % values. Figure 5 demonstrates that PET-G and PLA have higher elongation at break than ABS 5.88 and Nylon 6.2, indicating that PLA and PET-G have similar elongation at break.

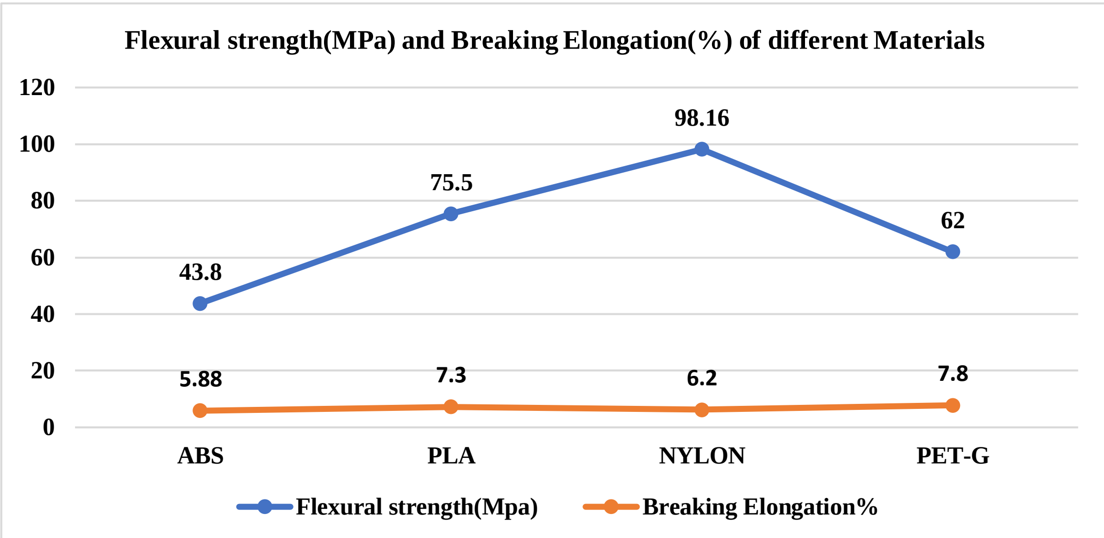

Figure.5 Flexural strength (MPa) and Breaking Elongation (%) of some materials [35]

VI. QUALITY ISSUES IN FDM

Following are the quality related issues needed to work in FDM:

- Most of the problems with FDM printing stem from the fact that it is a highly mechanical method in which fine-tuning the printer is essential. The most sensitive element of the operation is the interaction among the extruder/nozzle as well as the construction plate [35].
- To produce the desired product, fused deposition modeling involves layering molten filament material.
- The printing nozzle's right back paths are referred to as the stair-stepping effect, which can be understood on the product's surfaces due to the design of the operation (Fig.6). It refers to layer thickness;
  Cusp height is denoted by C, while the inclination across penetration depth and cusp altitude is denoted by alpha. As a result of these tracks forming terraces on the soil, average roughness values (Ra) in the micrometer range are relatively elevated [36].

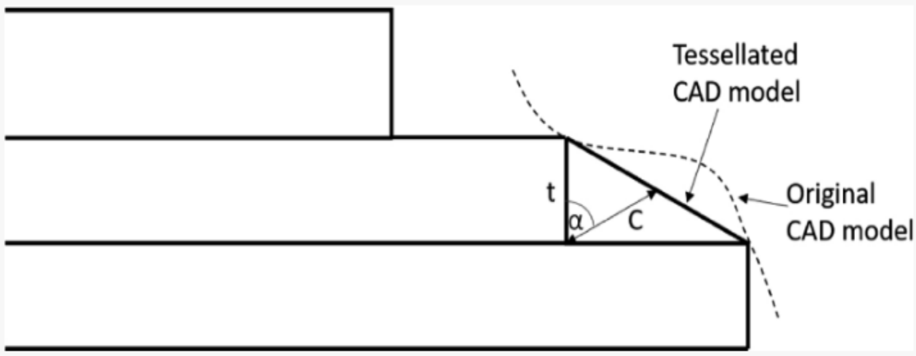

Fig. 1.4
Illustrating the staircasing effect of the FDM parts. In this case, C is known as cusp height, t is the layer thickness and α is the angle between the cusp height and layer height

Figure. 6 Showing the stair casting effect [36]

- Layer thickness of 3-D printed items surface morphology debugging tools and scanners are used to forecast, as well as material properties is reduced using different thread approaches [37].

VII. RESULT AND DISCUSSION

Different innovations for FDM are being created in the research work, along with process parameter optimization which is a major necessity for producing quality parts with enhanced material, mechanical, and thermal properties. There are also various types of FDM machines were developed, each with its unique set of parameters for the material flow capacity that should be employed for the optimal outcomes. Aside from commercial filament quality, the type of addition and compound ratios identified in this review paper have a significant impact on the physical qualities of products manufactured with hybrid filament. Given that a normal PLA filament's tensile modulus is predicted to be 50-60 MPa, any component manufactured from pure PLA filament in the identical cross-sections should have a tensile strength of 60 MPa. Experiments are being conducted to raise this value using various additives and additive ratios.

VIII. CONCLUSION

The structural features of hybrid fibrils or objects formed with various modifications to commercial items utilizing the FDM technique were the subject of this review study. The following conclusions are drawn from the findings of experimental studies: Aside from the same kind of additive, ingredient ratios get a major effect on the overall qualities of the material. When the same type of additives is injected to the same thread in varied proportions, the material's physical behavior can be significantly altered, while maximize the number of the ingredient by itself doesn't imply that the material's robustness will improve. The fiber employed as a polymeric matrix, as well as the variety of preservatives and constituent proportions, have a considerable influence on the mechanical qualities of the manufactured items, as shown by the experimental results. The FDM process and matrix composites technique have a variety of uses, as well as reinforced fibers that are commonly used and close to the material properties that can be achieved in academic research using various filaments, additives, and additive ratios.

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